BELLCOMM, INC.
1100 Seventeenth Street, N.W. Washington, D.C. 20036

SUBJECT: Effects of the Reduction of Operational Altitude on the AAP Payloads - Case 610

DATE: June 27, 1968

FROM: A. B. Baker

ABSTRACT

This memorandum presents quantitative estimates of the increase in payload which could be realized on AAP missions 1, 2, 3A, 3 and 4 by initiating the mission sequence at some altitude lower than the current baseline value of 230 nm. Using a mission profile similar to the ML-14 schedule, 3716 pounds of payload can be added to these missions by using an initial altitude of 220 nm.

For altitudes lower than 220 nm, propulsive maneuvers are probably required to maintain the cluster in orbit for eight months. However, despite the additional RCS propellant which must be expended to perform these maneuvers, total net payload increases up to 6635 pounds are realizable over the five missions.

(NASA-CR-96039) EFFECTS OF THE REDUCTION OF OPERATIONAL ALTITUDE ON THE AAP PAYLOADS (Bellcomm, Inc.) 26 p

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MEMORANDUM FOR FILE

I. Introduction

The purpose of this effort is to make a quantitative estimate of the payload gain which can be realized on the early AAP missions (1-4) by initiating these missions at lower altitudes than the current baseline value of 230 nm. The payload gains can be derived from two sources. On the CM/SM, an equivalent weight in usable payload may be realized from the reduction of propellant (both RCS and SPS) required to transfer to and deorbit from a lower altitude than that required in the baseline mission. The allowable payload on the Orbital Workshop (OWS) and the LM/ATM launches is increased if the insertion altitude is lower than that prescribed in the baseline mission. The analysis is complicated by the fact that both the payload gain and the rate of orbital decay vary inversely with altitude. Hence, acceptable operating altitudes must not only permit significant increases in payload but the decay rates associated with those altitudes must be small enough to permit reasonable delays in subsequent launches.

Payload gains for different altitude profiles were obtained by using the MSFC Orbital Lifetime Prediction Program (Reference 1) to determine the altitude of the AAP cluster at specific times, noting the deviation in altitude from the baseline mission at that point, and then translating that deviation into a difference in payload. Though these differences are only theoretical and based on -2σ predictions, they are sufficiently valid for use in comparing the different altitude profiles.

II. Derivation of Payload Gains

The Baseline Mission Profile used for this study is virtually identical to the sequence shown in Schedule ML-14, the only significant difference being that the former begins on September 1, 1970 rather than on November 1, 1970 as in ML-14. This difference however will have no noticeable effect upon the results.

The Baseline Mission Profile is shown in Figure 1. The Orbital Workshop will be launched on the first mission day (Transition Point A) and joined soon after by the AAP-1 CM/SM. The latter remains docked to the OWS for 28 days (Phase 1) and then returns to earth (Transition Point B). The OWS remains in a quiescent state for the next 62 days (Phase 2) and is then joined by the AAP-3A CM/SM (Transition Point C). The latter remains in orbit for 56 days (Phase 3) before returning to earth (Transition Point D). The OWS once again remains in a quiescent state (Phase 4), this time for 34 days. Next, the AAP-3 CM/SM and the AAP-4 LM/ATM rendezvous (and dock) with the OWS (Transition Point E). This phase of the mission (Phase 5) also lasts for 56 days and terminates when AAP-3 returns to earth (Transition Point F). As illustrated in the figure, the entire sequence from Point A to Point F requires 237 days or approximately eight months.

Using the physical characteristics of the mission modules listed in Table 1 (Reference 2) and the launch schedule given by the Baseline Mission Profile, the MSFC Orbital Lifetime Prediction Program was used to generate altitude profiles for different initial altitudes. The results are shown in Figure 2. Note that the curves represent the "guaranteed" or -2σ prediction, corresponding to the $+2\sigma$ prediction of solar activity for the time period. This worst-case lifetime condition was assumed throughout the study.

The current baseline mission calls for an initial altitude of 230 nm. Altitude deviations from this baseline are translated into payload differences for the CM/SM by calculating the difference in the amount of propellant required to perform orbit transfer and deorbit activities. For example, Figure 3 shows the amount of SPS propellant required to transfer the CM/SM from an 81 x 120 nm parking orbit via Hohmann ellipse to a circular orbit at the specified altitude. The curve shows that 1606 pounds of SPS propellant are required to transfer the spacecraft from the parking orbit to 230 nm. If the spacecraft is transferred to an altitude less than 230 nm, the propellant required for that transfer is less than 1606 pounds and the usable payload can be increased by the amount of the reduction in the propellant weight.

Similarly, Figure 4 shows the variation in propellant requirements to deorbit from different altitudes. The figure shows two curves, one for the SPS which is used as the primary system and one for the RCS which is used as the backup system. Since each system must carry sufficient propellant to perform the deorbit maneuver, any reduction in deorbit requirement will result in a reduction in both SPS and RCS propellants. The curves in Figure 4 are derived from the Δv requirements given in Reference 3 for the heads-down attitude. As above, the usable payload may be increased by the amount of the total reduction in propellant weight.

Unlike the CM/SM, the OWS will be inserted directly into the specified circular orbit. Assuming the LM/ATM is also inserted directly (the stable-orbit rendezvous mode), the deviations in insertion altitude from the baseline mission can be translated directly into payload differences for both unmanned launches. Figure 5 (Reference 4) shows the variation in payload capability with altitude for a typical AAP launch vehicle, SA 209. Changes in payload capability can be derived directly from the figure. The payload gain at each transition point for any altitude profile is found by first noting the change in altitude relative to the Baseline Altitude Profile at each transition point, and then using Figures 3-5 to determine the change in payload capability. The net payload gain for the profile is then the algebraic sum of these changes.

III. Mission Profiles

Figure 2 shows that the lifetime for the Baseline Altitude Profile is 406 days, well in excess of the 237 days required for the mission. If the mission sequence is initiated at altitudes less than 230 nm, the altitude at any time during the mission will be less than the altitude defined by the Baseline Altitude Profile for that time and hence a net payload gain can be realized for that profile. The overall lifetime for these altitude profiles will also be reduced however. Figure 2 shows that 220 nm is approximately the lowest initial altitude that would insure an eight-month lifetime (for the -2σ case). Greater payload savings might be realized using lower initial altitudes but the curves for these altitudes indicate that their overall lifetime would be less than eight months unless propulsion maneuvers were made periodically to maintain the spacecraft in orbit. Though such maneuvers may require significant amounts of propellant, the overall savings could, in some cases, be even greater than that estimated for those profiles with lifetimes greater than eight months. This study therefore investigated both types of profiles: "passive" profiles whose lifetimes are greater than eight months and "active" profiles in which orbit transfers are required during the mission to insure an eight-month lifetime.

A. 220 nm "Passive" Profile

The derivation of the payload savings which could be realized by using the 220 nm altitude profile rather than the baseline (230 nm) profile is illustrated in Table 2. At Transition Point A, the transfer of AAP-1 to a circular orbit at 220 nm rather than 230 nm requires 118 pounds less SPS propellant (Figure 3) which may be used for additional payload. Also at Point A, insertion of AAP-2 (OWS) into a 220 nm orbit results in an increase of 875 pounds in the payload capability of the AAP-2 launch vehicle (Figure 5).

At Transition Point B, AAP-1 must deorbit from 215 nm rather than from 227.5 nm as required in the Baseline Altitude Profile. Deorbit from 215 nm requires 42 less pounds of SPS propellant and 44 less pounds of RCS propellant than would have been required to deorbit from 227.5 nm (Figure 4). Therefore, the net payload gain at Transition Point B is the sum of these propellant reductions or 86 pounds. The payload gains at each of the remaining transition points are similarly derived and the total payload gain for the profile is the sum of these gains or 3716 pounds.

B. "Active" Mission Profiles

Use of the SM RCS for mid-mission propulsion maneuvers makes possible a wide spectrum of active altitude profiles which would fulfill the eight-month lifetime requirement. However, by considering some realistic constraints, it is possible to narrow the field of acceptable profiles and to use the methodology developed above to obtain an estimate of the potential payload gain. The constraints assumed for this effort are as follows:

1. The basic mission profile for all cases is defined by Figure 1.

2. All orbit transfers will be minimum-energy Hohmann transfers and will be performed at the beginning or end of a mission phase, i.e. at a transition point.

3. The insertion altitude of the OWS (Transition Point A) must be sufficient to insure that the workshop will not fall below 150 nm in 91 days. This constraint insures that the spacecraft will be in orbit at the scheduled beginning of the AAP-3A mission (Transition Point C) despite a failure of AAP-1.

4. The initial altitude of the CM/SM/OWS combination (Transition Point A) must be sufficient to insure that the workshop will remain above 150 nm at the end of 181 days. This constraint insures that the workshop will be in orbit at the scheduled beginning of the AAP-3/AAP-4 mission (Transition Point E) despite a failure of AAP-3A.

5. The altitude of the OWS at the beginning of Phase 5 (Transition Point E) shall be sufficient to insure an additional 20 days in orbit beyond the scheduled beginning of AAP-3/AAP-4. The purpose of this constraint is to insure that the OWS would still be available for the final revisit despite delays in the launching of AAP-3 or AAP-4.

6. The minimum altitude of the cluster during Phase 5 is 160 nm. Two of the experiments on the LM/ATM, S082 and S083, are designed to take measurements of the UV radiation from the sun. In order to keep the atmospheric attenuation of incident UV energy to less than 10%, a minimum altitude of 160 nm must be maintained (Reference 6).

Examination of Figures 3-5 show that by far the largest payload gains result from the reduced insertion requirements on the OWS and LM/ATM launch vehicles. Hence it is advantageous to use altitude profiles which, while consistent with the above constraints, will permit the insertion of the OWS and LM/ATM into as low an orbit as possible.

Six profiles which satisfy these constraints were examined in detail. They are summarized in Table 3 and illustrated in Figures 6 through 11. The first three profiles represent variations of a "nominal" mission, that is the mission described by the Baseline Mission Profile in Figure 1. In each of these missions, the OWS is first inserted into a circular orbit of 197.5 nm, the lowest altitude which will satisfy constraint #3. AAP-1 is soon docked to the OWS and the combination is transferred to a circular orbit at 212.5 nm, the lowest altitude that will satisfy constraint #4. As shown in Figure 6, Profile 1 requires only one additional orbit transfer which occurs at the beginning of Phase 3. In Profile 2 (Figure 7), the orbit transfer is delayed until the end of Phase 3. Profile 3 (Figure 8) requires two additional orbit transfers which occur at the beginning of the third and fifth phases.

The net payload savings for these profiles are derived by the same methods used to obtain the savings for the 220 nm passive profile. The derivation is illustrated for Profile 1 in Table 4. The net gains for insertion and deorbit activities are derived as in Table 2. The negative number associated with each of the orbit transfers indicates the amount of additional RCS propellant that will have to be provided to transfer the cluster to the required altitude. Each total includes the amount required for the actual transfer plus the amount required to orient the cluster before and after the transfer (Reference 5). The algebraic sum of the individual gains shows that a total of 5343 pounds could be added to the payloads if Profile 1 is used. Similarly, 5087 or 6635 pounds could be added by using Profiles 2 or 3 respectively.

The remaining three profiles listed in Table 3 are contingency profiles. Each assumes failure of a CM/SM, either AAP-1 or AAP-3A, to perform the required orbit transfer. Profiles 4 and 5 (Figures 9 and 10) assume an AAP-1 failure. In that case, the workshop altitude will decay from 197.5 to 150 nm at the beginning of Phase 3 when the OWS is joined by AAP-3A. In Profile 4, only one orbit transfer is used. The combination is transferred to 205 nm and decays to 162.5 nm by the end of the mission. Profile 5 assumes one orbit transfer at the beginning of Phase 3 but only to 195 nm. The altitude of the OWS will therefore be reduced to 165 nm at the beginning of Phase 5 and hence another transfer is necessary (to 185 nm) to insure that the cluster will still be above 160 nm by the end of the mission. Using the method developed above, the net payload savings for profiles 4, 5 and 6 are 4412, 5700 and 6634 pounds respectively.

IV. Summary

A summary of the payload gains for the different altitude profiles is shown in Table 5. The table shows the net payload gain for each mission module in each profile. Negative numbers indicate the net amount of propellant that would have to be added to the particular spacecraft. Note that the numbers marked with an asterisk are not true additional propellant requirements but are theoretical additions obtained from the baseline mission. They are included for consistency so that the numerical total of Net Payload Gain will reflect the true relative merit of the particular profiles despite the absence of a mission module.

The table shows that there is a distinct payload advantage in using an active altitude profile. Active Profile 3, requiring three orbit transfers, is the most promising in terms of overall payload gain, but even the three contingency profiles may realize a greater net gain than the 220 nm passive profile. No attempt has been made to maximize the potential gain by optimizing these profiles and it is quite possible that there are other profiles which have even greater potential savings.

V. Conclusions

It is apparent from the preceding discussion that any estimate of payload increase for the five AAP missions depends upon the assumptions made for those mission constraints which effect operating altitude. These constraints include:

1. the overall lifetime required,

2. the amount of scheduling flexibility desired,

3. experimental and operational constraints which determine the range of operating altitude.

As one might expect, the achievable payload increase for the five missions varies inversely with the requirements inherent in these constraints. Basically, payload can be increased by performing transitional activities at lower altitudes. However the operating altitude increases as lifetime and/or scheduling requirements increase. Hence, the selection of an altitude profile is a trade-off between how much more payload is desired and how much the constraints can be eased. There is a large number of possible altitude profiles and this effort therefore assumed constraints which produced profiles that are representative of what can be achieved.

It should be noted that there may be a number of obstacles to the physical realization of these payload gains. One particular problem is the feasibility of changing the RCS and SPS propellant loads in response to the profile's change in requirements. As stated above, most of the net payload gain for any profile is derived from reducing the insertion requirements on the OWS and LM/ATM launch vehicles. In many cases, the propellant requirement on the manned missions actually increases quite significantly, particularly the RCS requirements. For example, the table shows that a net payload gain of 5087 pounds could be realized by using Active Profile 2 but that the AAP-3A propellant requirement for that profile increases 248 pounds. Similarly a net gain of 4412 pounds can be realized with Profile 4 but again the AAP-3A propellant requirement increases 902 pounds.

The situation becomes even more complex when one realizes that examining only the net propellant requirement change shown in Table 5 can be quite deceptive. The table shows that AAP-3 requires an additional 195 pounds of propellant if Active Profile 3 is used. However Table 6, which summarizes the required propellant change in the manned missions for each profile, shows that AAP-3 actually requires an additional 836 pounds of RCS propellant while at the same time reducing the SPS propellant requirement by 641 pounds. (Positive numbers in Table 6 indicate additional propellant required, negative numbers indicate a reduction in requirement.) One possible means of minimizing the changes to the CM/SM spacecraft is to adjust the altitude profile to equalize the additional propellant requirements in the three manned missions. Though it would undoubtedly sacrifice overall payload gain, this method would lower the extreme propellant additions required on some of the manned missions and make the resulting requirements on the three spacecraft more uniform and easier to realize. In any event, the extent of the physical modification required to accommodate the changes described in Table 6, along with their impact on the remaining physical and operating characteristics of the CM/SM and the other mission modules, should be thoroughly investigated before a commitment to this approach is made.

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1025-ABB-dcs

A. B. Baker

Attachments

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"Variation in S-IVB Optimal Second MR-Shift Time with Orbital Altitude for AAP"
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6. Private communications with T. C. Tweedie, Jr., Bellcomm, Inc.

TABLE 1

CHARACTERISTICS OF THE AAP MISSION MODULES*

Phase	Configuration	Mass (lbs)	C_DA (sq ft)	$\frac{M}{C_DA}$ (lbs/sq ft)
1	OWS + CM/SM	85459.014	5367.96	15.92
2	OWS	56546.009	3743.15	15.11
3	OWS + CM/SM	85459.014	5367.96	15.92
4	OWS	56546.009	3743.15	15.11
5	OWS + CM/SM + LM/ATM	116236.014	6499.25	17.88

*Reference 2

TABLE 2

PAYLOAD GAIN FOR THE 220 NM PASSIVE ALTITUDE PROFILE

Transition Point	Activity	Altitude (nm)	Net Payload Gain (lbs)
A	AAP-2 Insertion	220	875
	AAP-1 Insertion	220	118
B	AAP-1 Deorbit	215	86
C	AAP-3A Insertion	205	180
D	AAP-3A Deorbit	195	115
E	AAP-4 Insertion	187.5	1875
	AAP-3 Insertion	187.5	271
F	AAP-3 Deorbit	165	196
TOTAL PAYLOAD GAIN			3716

TABLE 3

AAP ACTIVE ALTITUDE PROFILES

Profile #	Mission Type	Description
1	Nominal Mission	2 Orbit Transfers, at 1 and 91 days
2	Nominal Mission	2 Orbit Transfers, at 1 and 147 days
3	Nominal Mission	3 Orbit Transfers at 1, 91, and 181 days
4	Contingency Mission AAP-1 Failure	1 Orbit Transfer at 91 days
5	Contingency Mission AAP-1 Failure	2 Orbit Transfers, at 91 and 181 days
6	Contingency Mission AAP-2 Failure	2 Orbit Transfers, at 1 and 181 days

TABLE 4

PAYLOAD GAIN FOR ACTIVE ALTITUDE PROFILE 1

Transition Point	Activity	Altitude (nm)	Net Payload Gain (lbs)
A	AAP-2 Insertion	197.5	2750
	AAP-1 Insertion	197.5	388
	Orbit Transfer	197.5/212.5	-527
B	AAP-1 Deorbit	207.5	142
C	AAP-3A Insertion	192.5	331
	Orbit Transfer	192.5/205	-438
D	AAP-3A Deorbit	195	115
E	AAP-4 Insertion	185	2075
	AAP-3 Insertion	185	302
F	AAP-3A Deorbit	162.5	205
TOTAL PAYLOAD GAIN			5343

TABLE 5

AAP NET PAYLOAD GAINS

Profile	Payload Gain** AAP-1 CM/SM	AAP-2 OWS	AAP-3A CM/SM	AAP-3 CM/SM	AAP-4 LM/ATM	Net Gain
220 nm Passive Profile	204	875	295	467	1875	3716
Active Profile 1	3	2750	8	507	2075	5343
Active Profile 2	3	2750	-248	507	2075	5087
Active Profile 3	3	2750	402	-195	3675	6635
Active Profile 4	-18*	2750	-902	507	2075	4412
Active Profile 5	-18*	2750	-512	-195	3675	5700
Active Profile 6	3	2750	-242*	-702	4825	6634

*Theoretical Loss; mission aborted
**Pounds

TABLE 6

SM PROPELLANT REQUIREMENT CHANGES*

Mode	AAP-1		AAP-3A		AAP-3	
	RCS	SPS	RCS	SPS	RCS	SPS
220 nm Passive Profile	-44	-160	-63	-232	-107	-360
Active Profile 1	+450	-453	+375	-383	-112	-395
Active Profile 2	+450	-453	+631	-383	-112	-395
Active Profile 3	+450	-453	+6	-408	+836	-641
Active Profile 4	---	---	+1809	-907	-112	-395
Active Profile 5	---	---	+1444	-932	+836	-641
Active Profile 6	+450	-453	---	---	+1530	-828

*Pounds

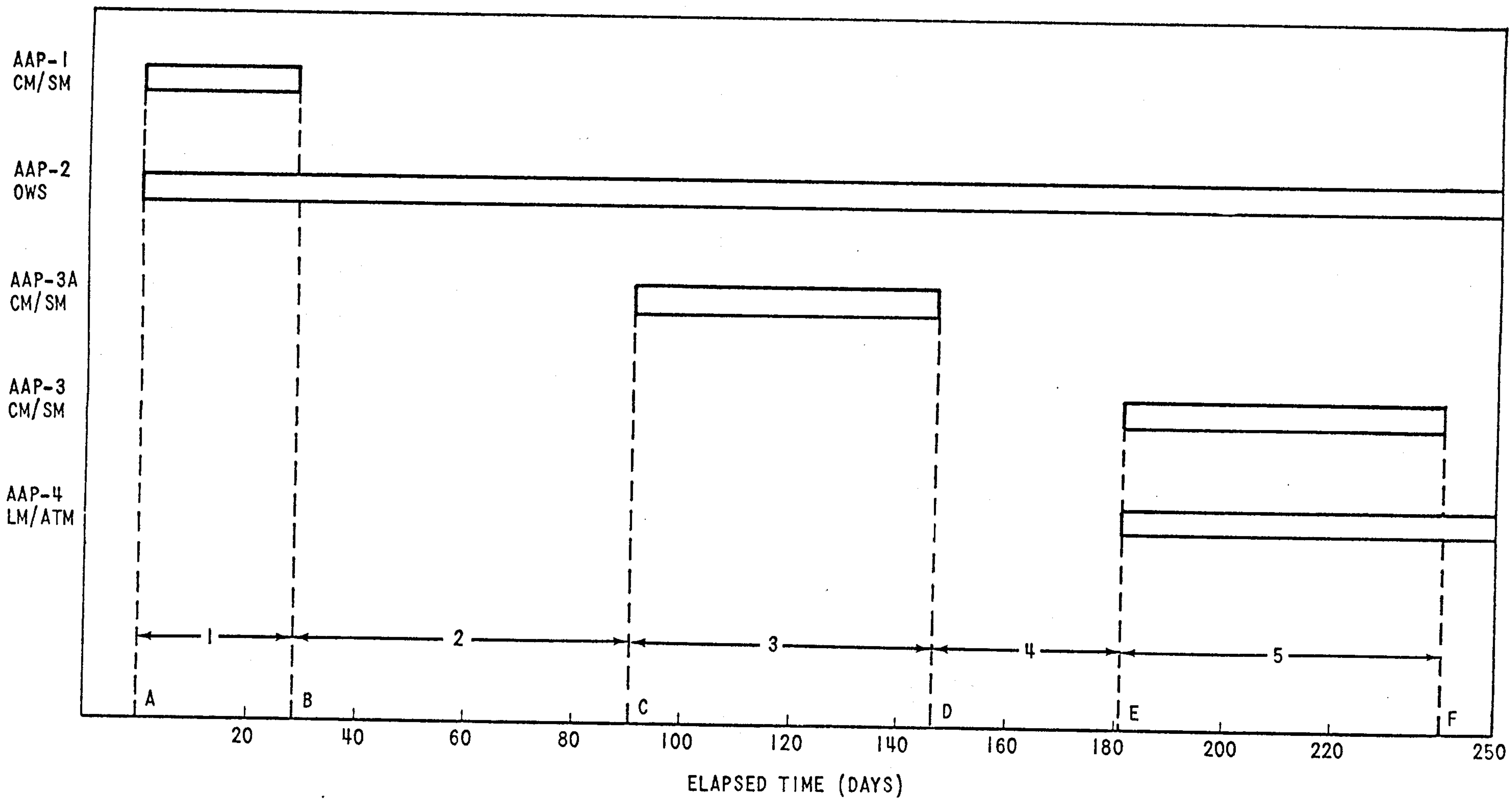

FIGURE 1 - BASELINE MISSION PROFILE

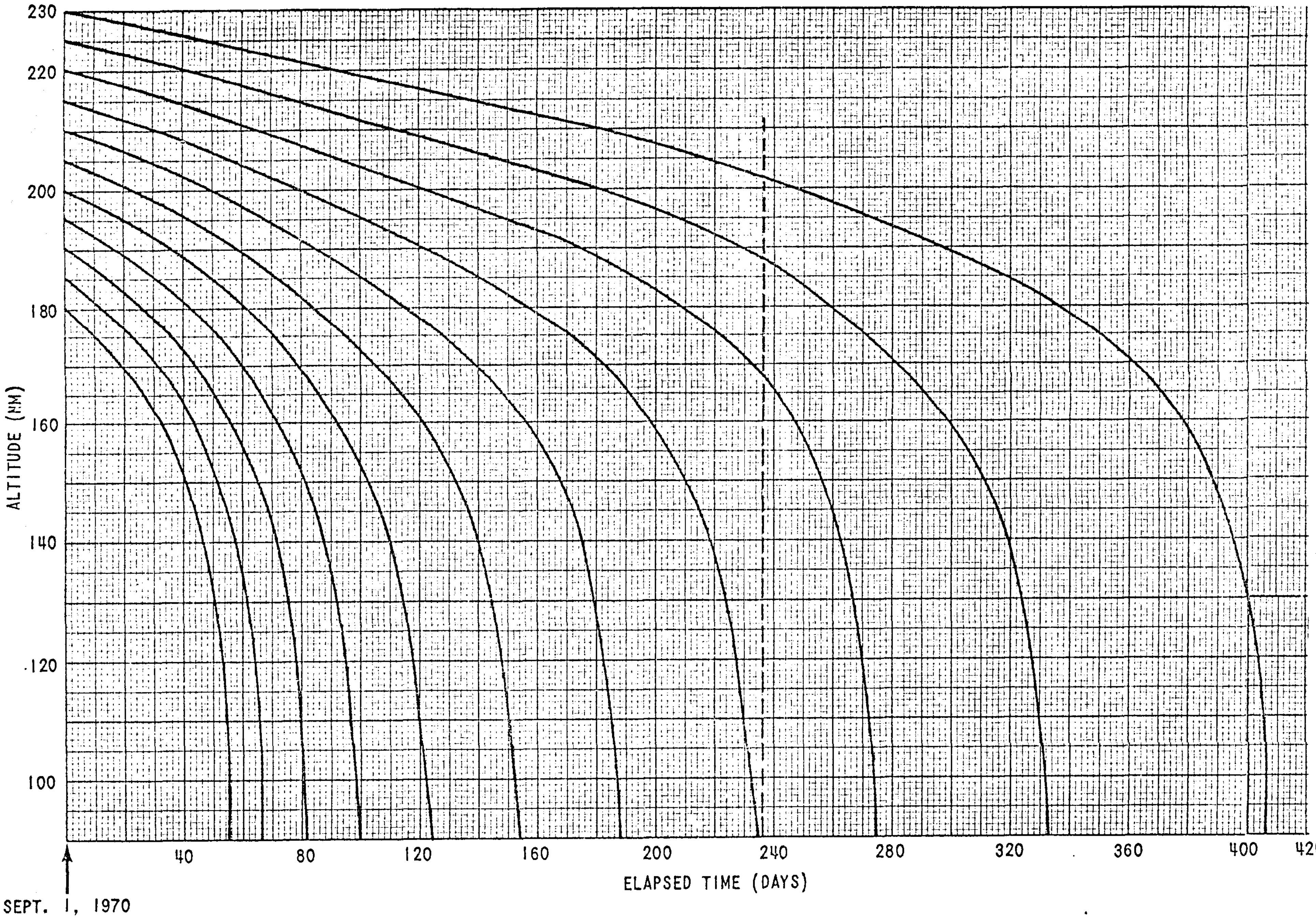

FIGURE 2 - MINUS 2 SIGMA ALTITUDE PROFILES FOR THE BASELINE MISSION

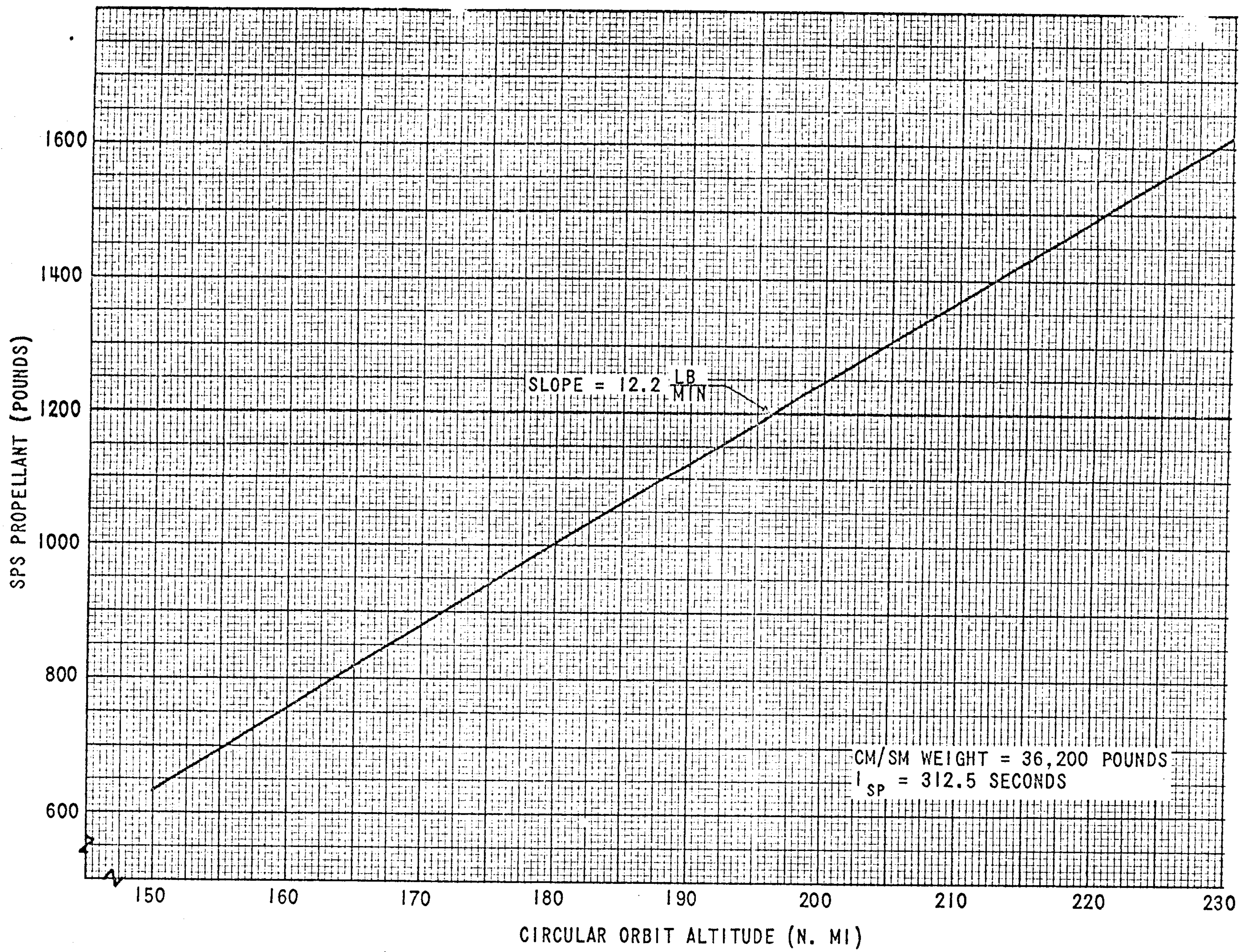

FIGURE 3 - SPS PROPELLANT REQUIREMENTS FOR CM/SM TRANSFER
FROM 81 x 120 N. MI PARKING ORBIT

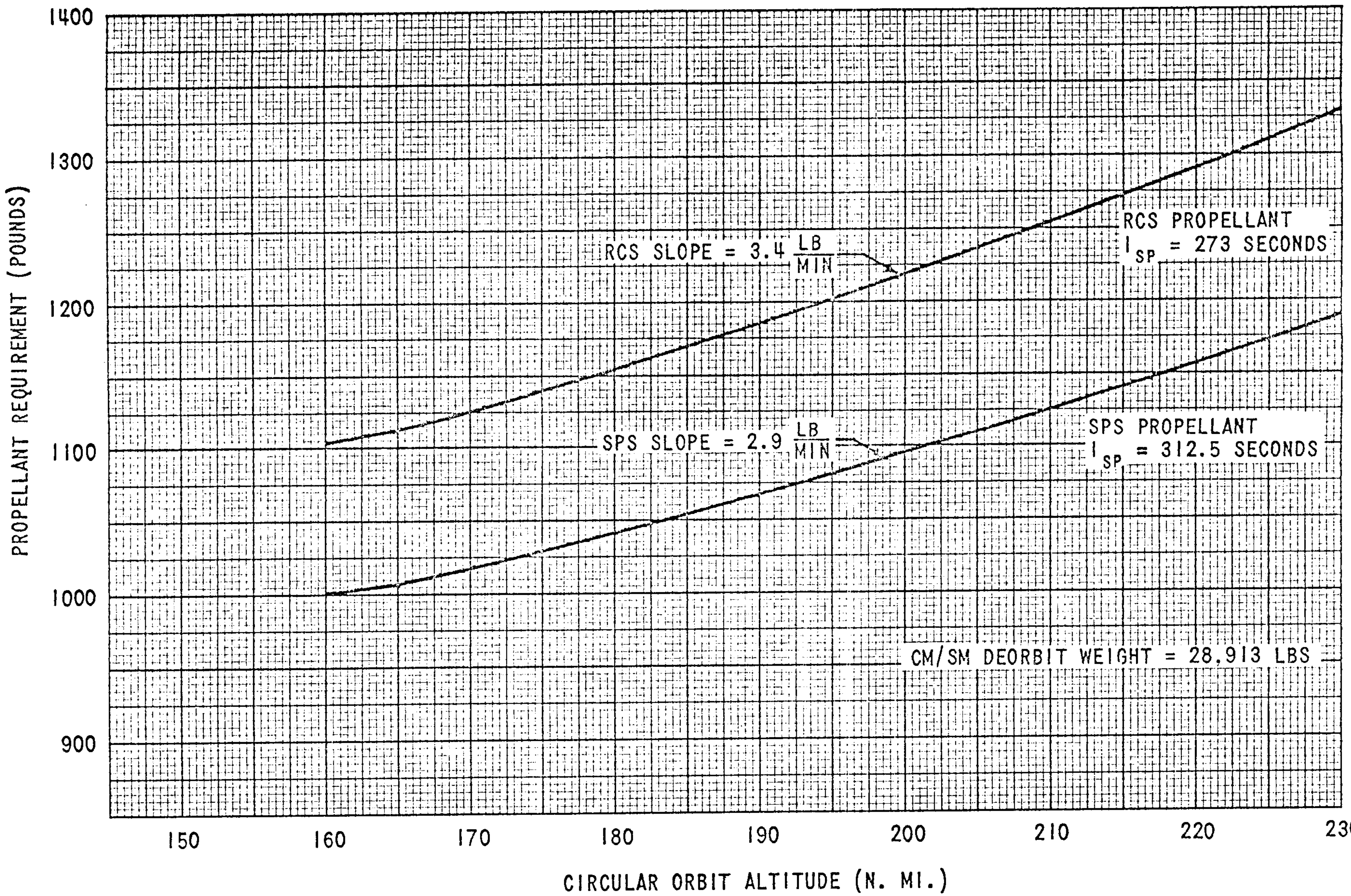

FIGURE 4 - DEORBIT PROPELLANT REQUIREMENTS

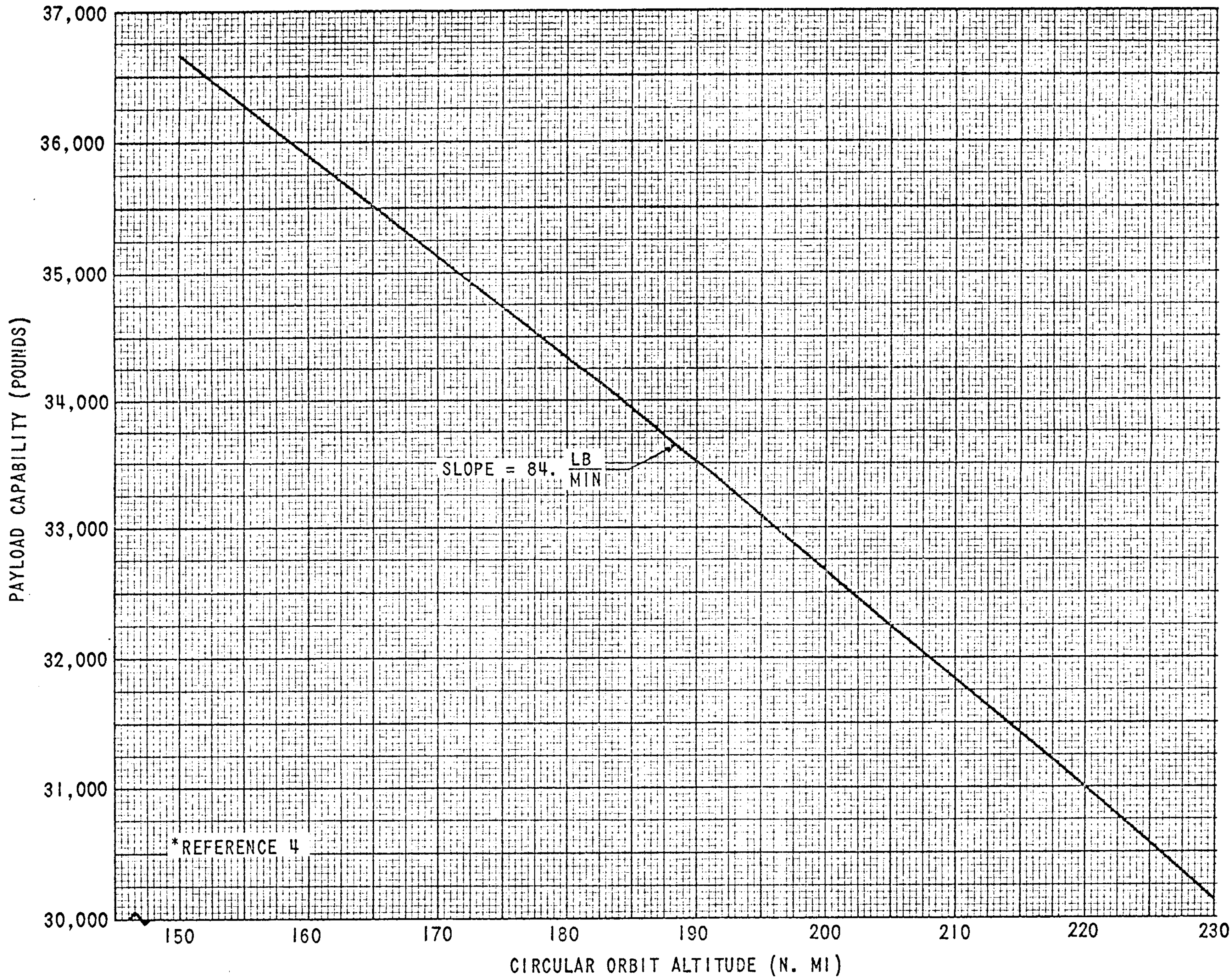

FIGURE 5 - PAYLOAD CAPABILITY OF LAUNCH VEHICLE 209*

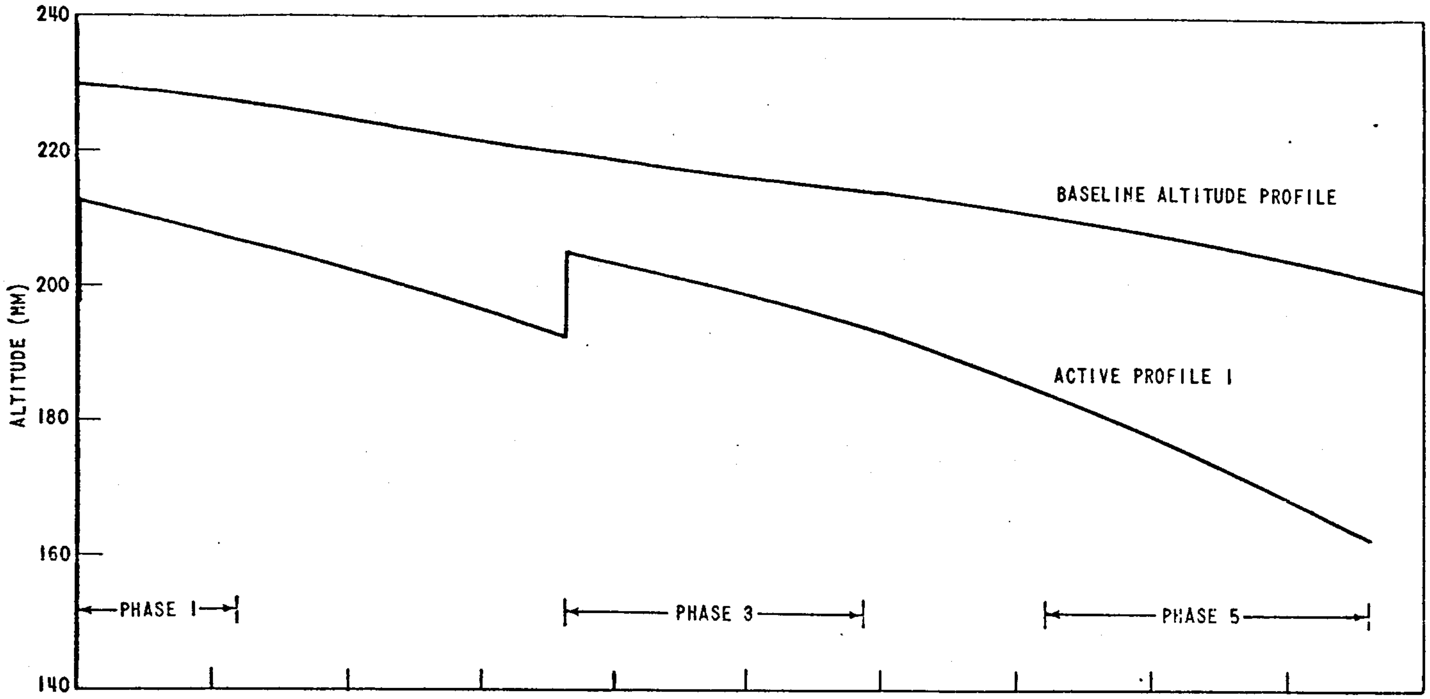

FIGURE 6 - ACTIVE ALTITUDE PROFILE 1

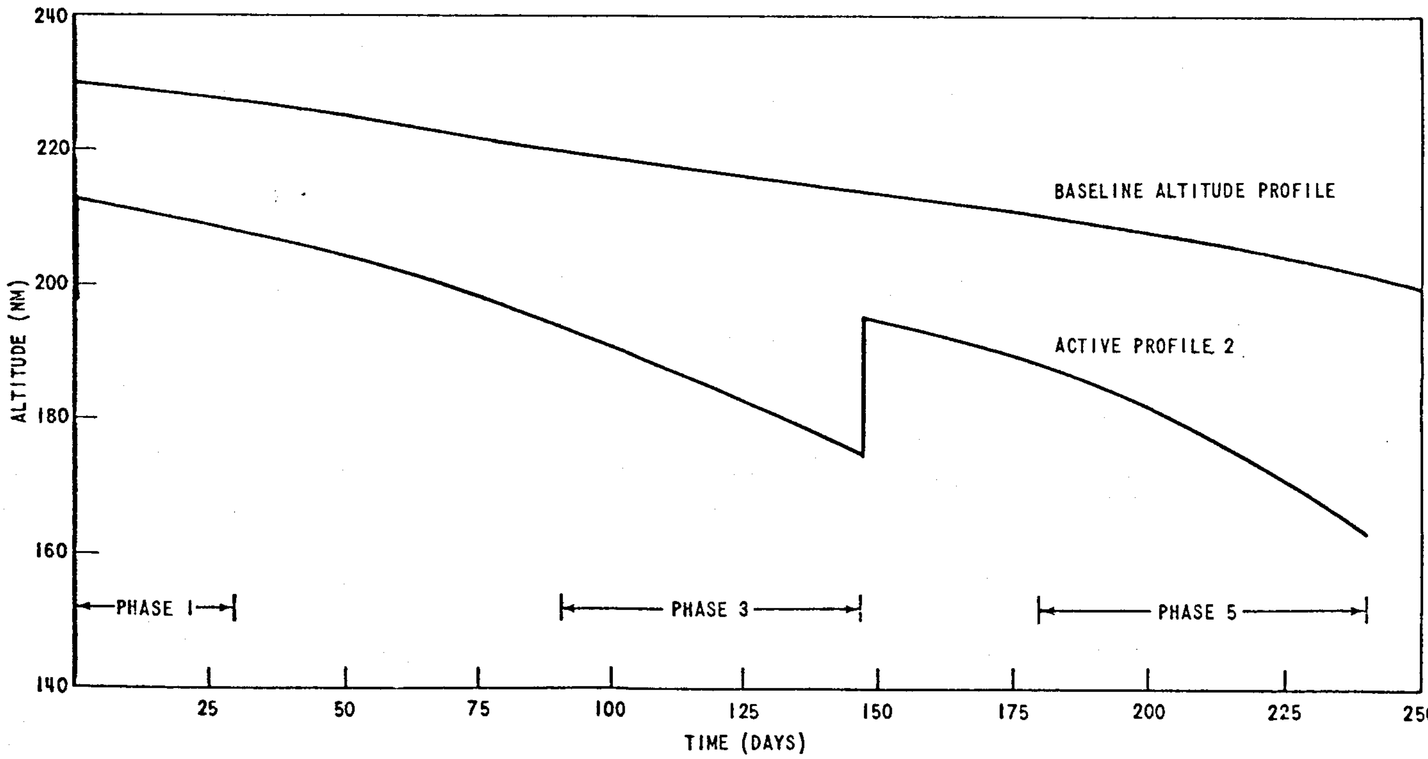

FIGURE 7 - ACTIVE ALTITUDE PROFILE 2

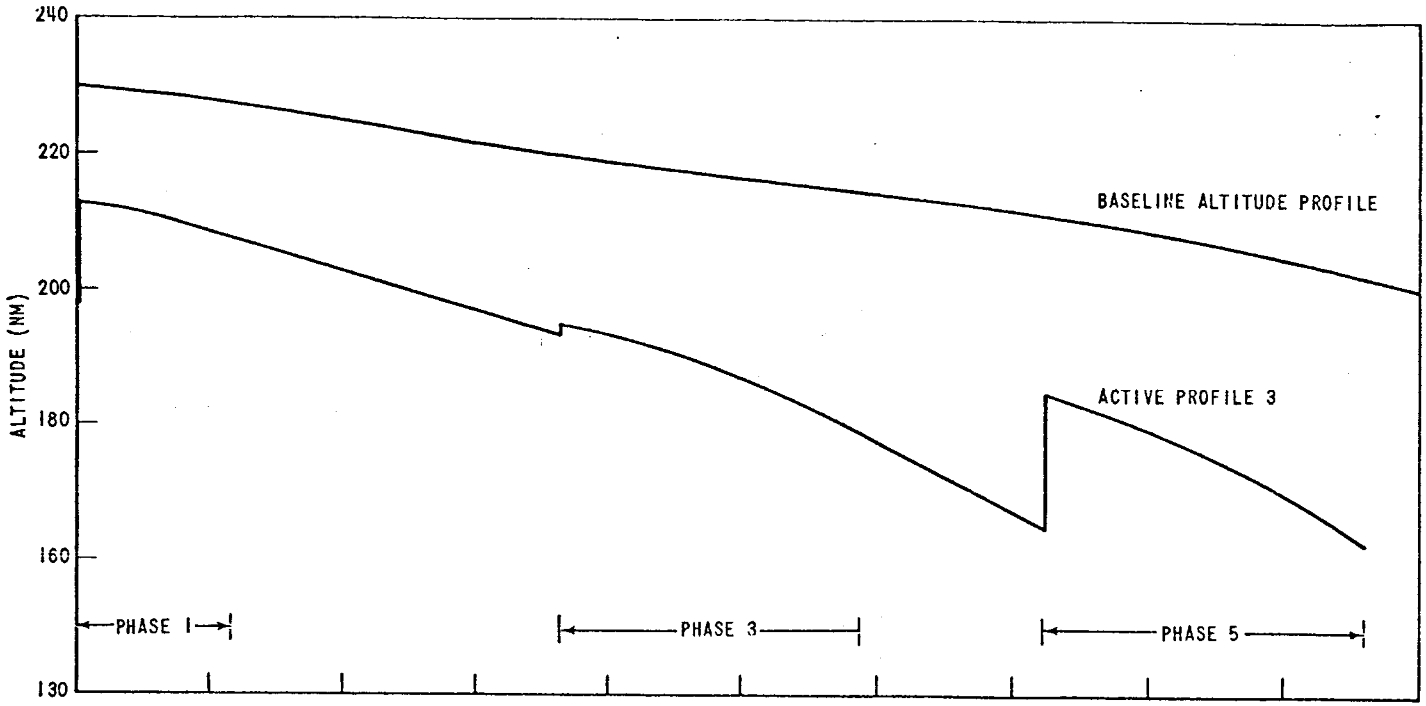

FIGURE 8 - ACTIVE ALTITUDE PROFILE 3

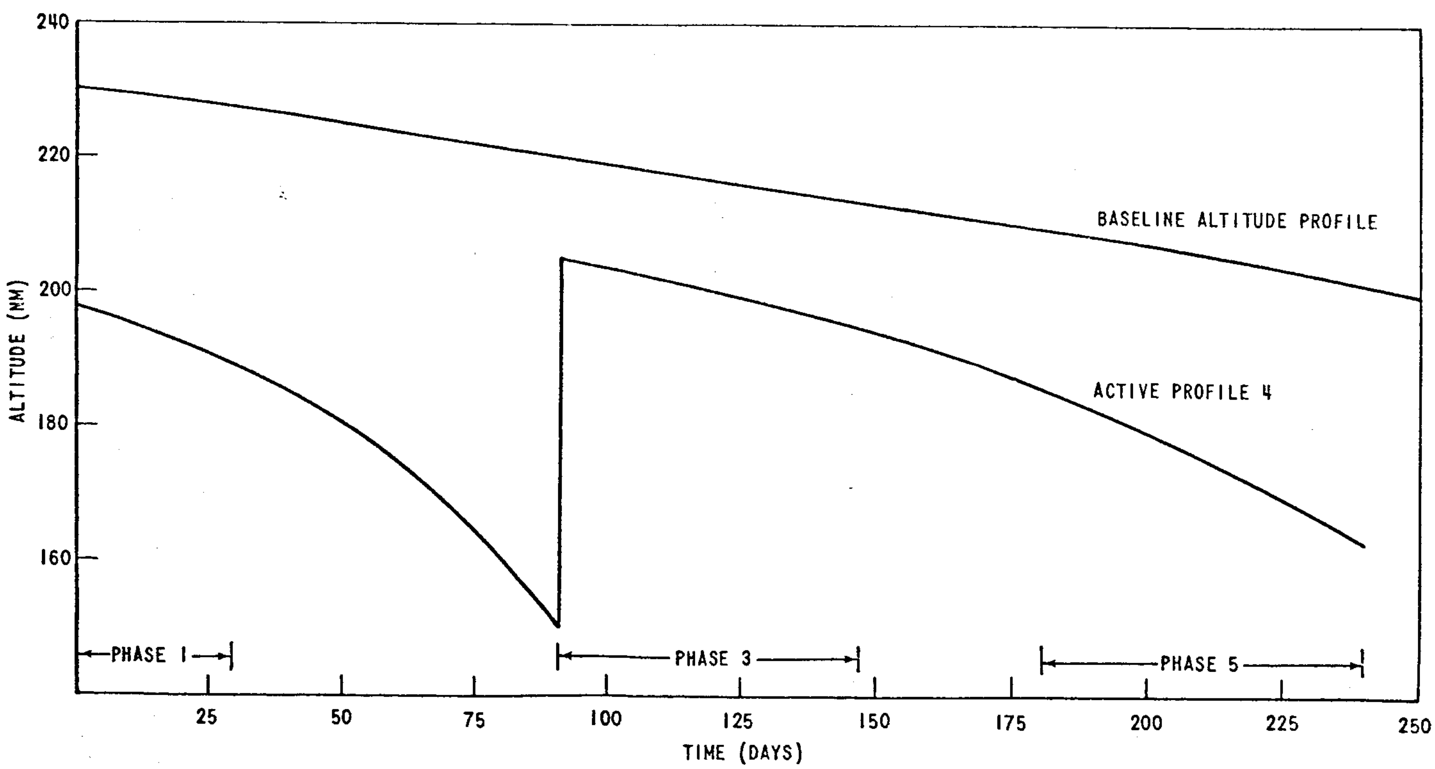

FIGURE 9 - ACTIVE ALTITUDE PROFILE 4

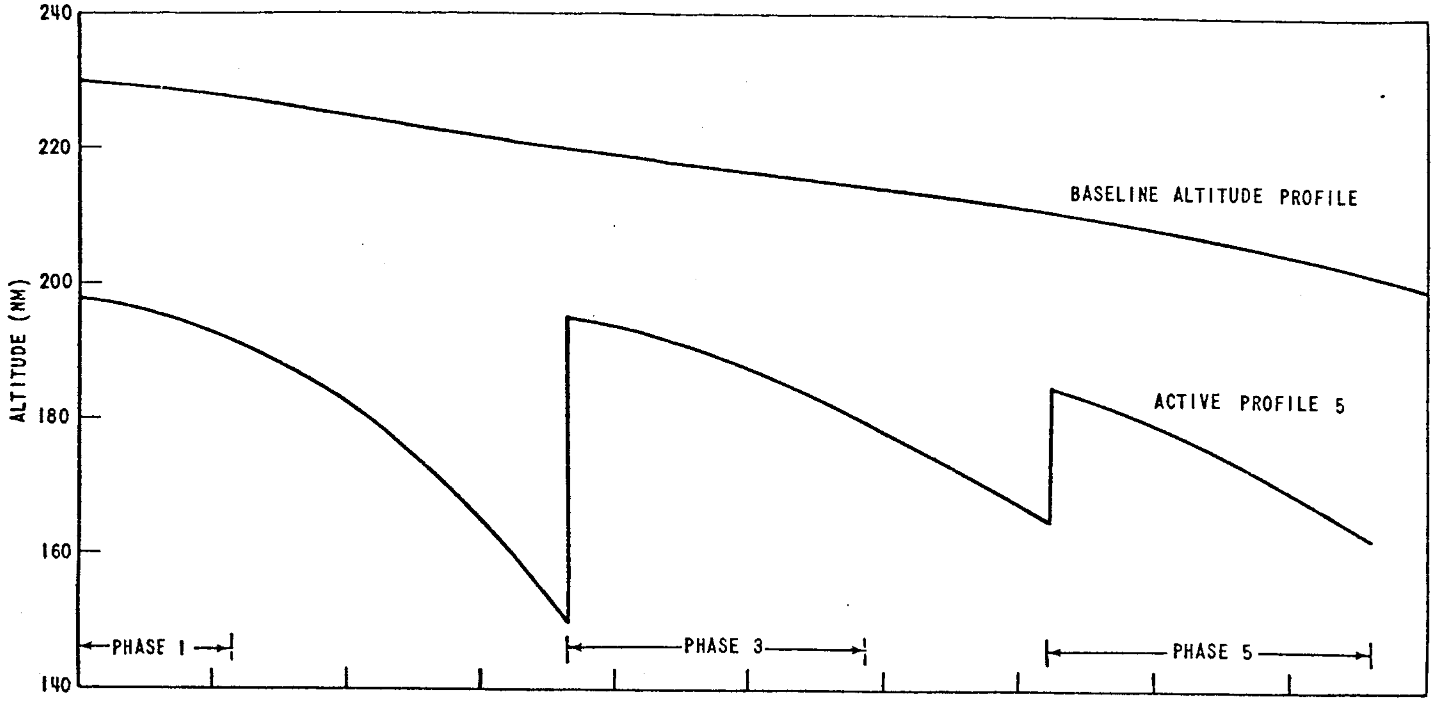

FIGURE 10. - ACTIVE ALTITUDE PROFILE 5.

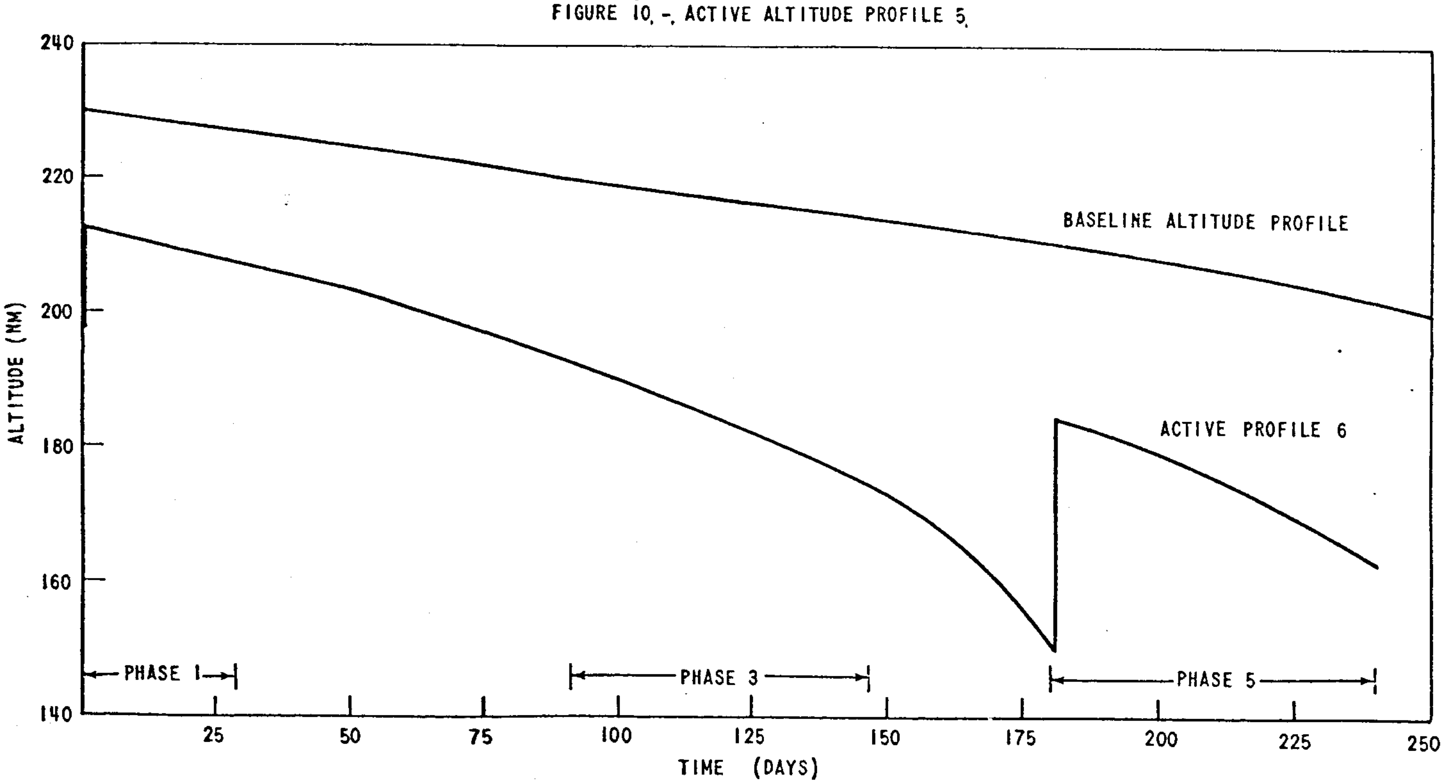

FIGURE 11 - ACTIVE ALTITUDE PROFILE 6.

BELLCOMM, INC.

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From: A. B. Baker

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